SARA's Direct Carbon Fuel Cell

History, Status, and Joint Industry Program

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SARA

What Are You Going To Hear?

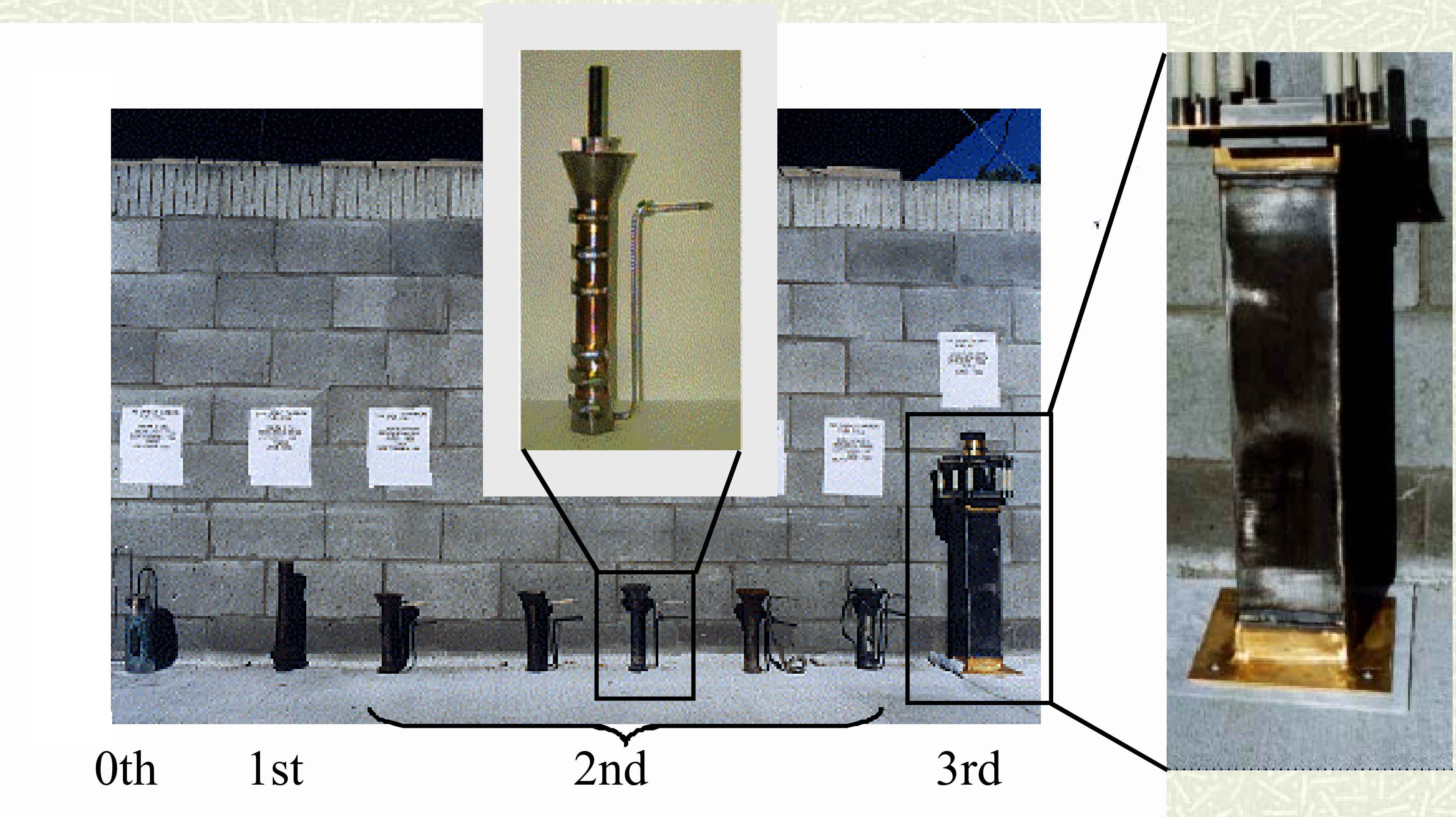
- SARA's DCFC is a high efficiency, medium temperature, scalable technology
- Capital costs will be attractive – no exotic materials or manufacturing processes
- Technology is suited to stationary power applications
- The ultimate goal is building multi-100 MW power plants using DCFC
- We have formed a Joint Industry Program with our industrial partner American Electric Power to further the development of the DCFC
- We have demonstrated good performance in a DCFC at a scale large enough that it appears to be promising for stationary power generation

Direct Carbon Fuel Cell (DCFC) Technology and Status

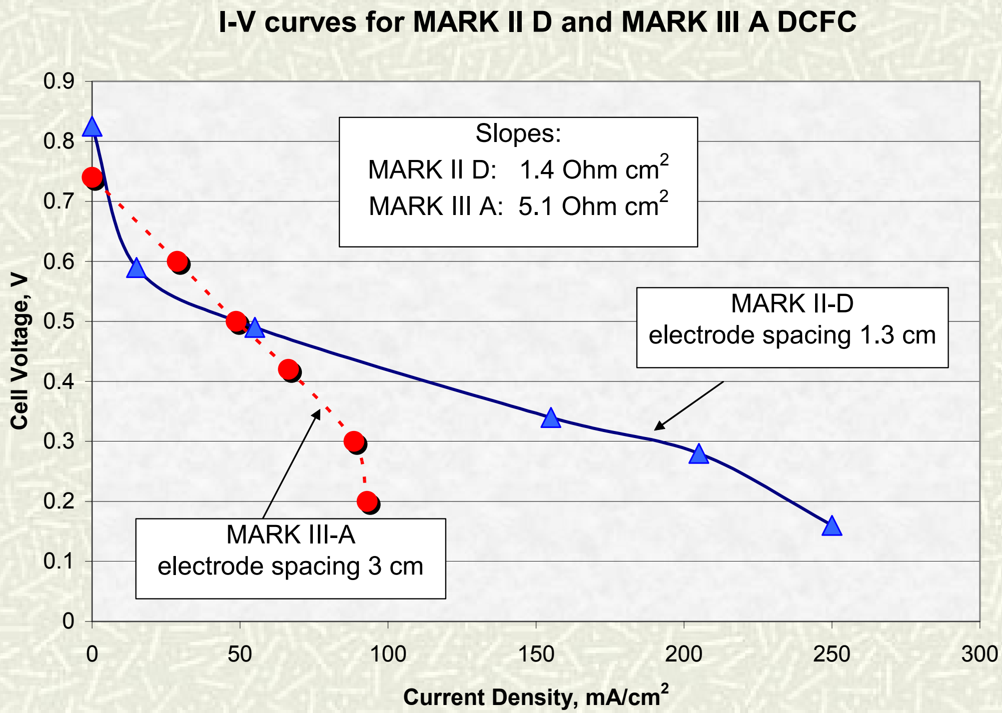
Historical Background of DCFC

- Dr. William Jacques 1896 patent "Method of converting potential energy of carbon into electricity"
- For the next 40 years (until 1939), European researchers unsuccessfully attempted to duplicate Jacques' results
  - Including Dr. Fritz Haber, and later, Dr. Edward Bauer
- ERDA and DOE funded carbon-air fuel cell research with the Stanford Research Institute (SRI), under the direction of Dr. Robert Weaver (1973)
  - Dr. Weaver's team succeeded in duplicating Dr. Jacques original performance
- SARA began DCFC research in mid-1990's
  - 4 generations of cells with increasing levels of success
  - Sodium hydroxide electrolyte and solid graphite fuel
- LLNL began Carbon Fuel Cell research in late-1990's
  - Molten carbonate electrolyte and turbostatic carbon particulate

Proof-of-Concept Prototypes



Performance of DCFC Prototypes



DCFC Prototype Performance

- Average output power in Mark III-A
  - 12-20 watts (over 540 hours)
  - Peak output power (sustained for 5 to 10 seconds)
    - *35-50 watts*
- Average voltage, current & current densities
  - 300mV @ 40amps in Mark III-A
  - 100 mA/cm^2 in Mark III-A
  - 250 mA/cm^2 in Mark II-D
- Efficiency
  - 60% measured in the non-optimized Mark III
  - Maximum efficiency of DCFC ~ 85-90%
  - Efficiency of single stage Coal-combustion power plants: 25-40%
  - Practical DCFC plant ~ 70-75%

Enabling Processes Mentioned in the Patent

- Titanium doped steel for cathode
  - TiFe Oxides are Degenerate Semiconductors
  - Coats and Protects the Cathode Surface and Enables Conduction
  - Ti *may* have contributed to Dr. Jacques initial success – Norway Iron
  - Patent Pending
- Humidity in atmosphere above melt
  - Makes molten sodium hydroxide acidic
  - Reduces corrosion rate to nearly zero
  - Substantially reduces Carbonate production
  - Metal pickling industry – 15-20 years at near zero corrosion
  - Patent Pending

Preliminary Cell Stack Cost Estimates

- Cell is welded steel structure
  - Industry average is \$2.50 per pound for welded steel structures using mild steel and common welding techniques
- 2 cm^2 per amp, producing about 0.5 volts at current density of .5 Amp/cm^2
- 1 kW cell needs 4000 cm^2 cathode area at .5 cm wall thickness – 126 in^3 cathode area
- Double this for rest of cell – 250 in^3 of steel ~ 75 pounds ~ \$200

Preliminary Cost Comparisons

DCFC Plant Capital Cost Comparison With Traditional Coal Fired Plant

DCFC Capital Item	Cost ($/kW)
Coal Receving	50
Coal Handling/Clean	30
DCFC Stack	200
Power Conversion	200
Power Distribution	40
Controls and Inst.	30
Miscellaneous	150
Contingency	100
Land, Permits, etc.	50
Total	850

Traditional Capital Item (from IEA Grenhouse Gas R&D Paper)	Cost ($/kW)
Coal Receiving	48
Coal Handling	6
Boiler	248
Electrostatic Precip.	48
Steam Turbine	214
Cooling System	22
Water Treatment	14
Power Distribution	40
Controls and Inst.	22
Flue Gas Desulfurization	112
Miscellaneous	144
Contingency	92
Land, permits, etc.	50
Total	1060

Intellectual Property (IP) Status

- SARA received US Patent #6,200,697
  - *"Carbon-Air Fuel Cell" March 2001*
- We are expanding DCFC patent portfolio
  - 4 new patents applied for
    - Titanium doping of steel
    - Humid atmosphere above melt – acidification of electrolyte
    - New, more efficient, potentially higher current density design
    - Liquid hydrocarbon reformer that makes solid carbon (Navy)
  - Other areas - contaminant removal, electrolyte optimization, geometry optimization, material selection, power electronics, …

DCFC
Development and Business Plan

Joint Industry Program (JIP)

- Objective
  - Accelerate DCFC development by recruiting organizations with strong Coal or Carbon interest
    - Utilities, Coal producers, Integrated Energy Companies
  - Position DCFC for Venture Capital in 5 years
- Advantages
  - Stable financing for DCFC development
  - Access to a wide range of technical resources
    - Laboratories, technologists, facilities
- Advisory Board to Guide JIP
  - Votes based on level of investment
  - American Electric Power is Founding Member
  - DOE monitor has a seat on Advisory Board
- JIP becomes DCFC Inc. toward end of 5-yr Program

Business Structure & Finance - JIP

- Phase I (first 5-years)
  - Joint Industry Program (JIP) staffed and managed within SARA
  - Intellectual Property will be expanded and protected (US and International)
  - JIP Advisory Board to review and recommend R&D direction
  - Government funds applied for during this period
    - DOE funding through NETL
    - Navy funding through ONR and NSWC Carderock

Business Structure & Finance - DCFC, Inc.

- Phase II (second 5-years)
  - DCFC becomes an independent Company as the second round of financing is secured (Venture Capital)
  - SARA transfers key personnel, IP, and capital assets to DCFC, Inc. in exchange for transaction costs and equity
  - Government funds for pilot plant (DOE and Navy)
  - Licensing revenues as power plants become operational
  - Board of Directors of the new company review and approve the research and business direction

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- We would like to invite Workshop Participants from Industry to join our JIP